Photoelasticity with Gigahertz and Terahertz Illumination.

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Abstract. The advent of high power tunable GHz and THz sources has enabled the development of a highly flexible polariscope system capable of measuring a range of different material parameters in materials which are opaque at visible wavelengths. In this paper we present the details of the polariscope system and demonstrate the measurement of the stress-optic coefficient of yttria-partially stabilized zirconia (YTZP) and yttria-stabilized zirconia (YSZ) coatings with a view to identifying potential failure mechanisms in thermal barrier coatings (TBCs).

Introduction

The use of GHz and THz illumination allows the non-destructive investigation of optically opaque layered structures, such as ceramic thermal barrier coatings. The measurement of the mechanical-loading-dependent material parameters of these coating allows some insight into their internal structure as well as potential failure mechanisms. In this paper we present a polariscope system [1, 2] capable of measuring the transmission and reflection spectra of ceramic substrates under different mechanical loads and, hence, determining the stress-optic coefficient of an YSZ TBC.

GHz/THz Reflection Polariscope

The two configurations of the polariscope system, shown in Figure 1, allow the measurement of the transmission and reflection from a sample which is placed under load by a DeBen tensile test rig.

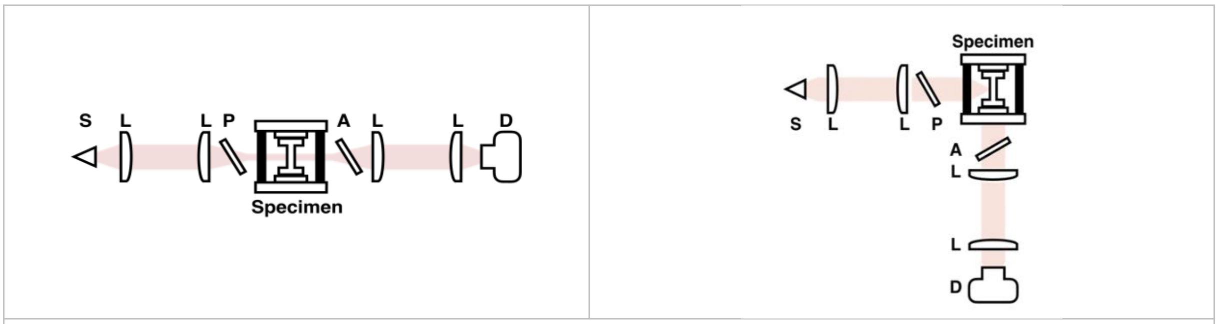

Figure 1: Transmission (Left) and Reflection (Right) polariscope configurations. S – Source; L – Plano-convex lenses; P – Linear Polarizers; D – Detector.

Translation (in X, Y and Z) of the tensile test rig within the focal plane of the optical system allows a composite map of the sample transmissivity/reflectivity to be built up as a function of frequency.

Fringe Analysis of YTZP samples.

Figure 2 shows the results of a frequency scan in reflection for two different unloaded ceramic samples – a bulk YTZP sample and a coated YSZ thermal barrier coating.

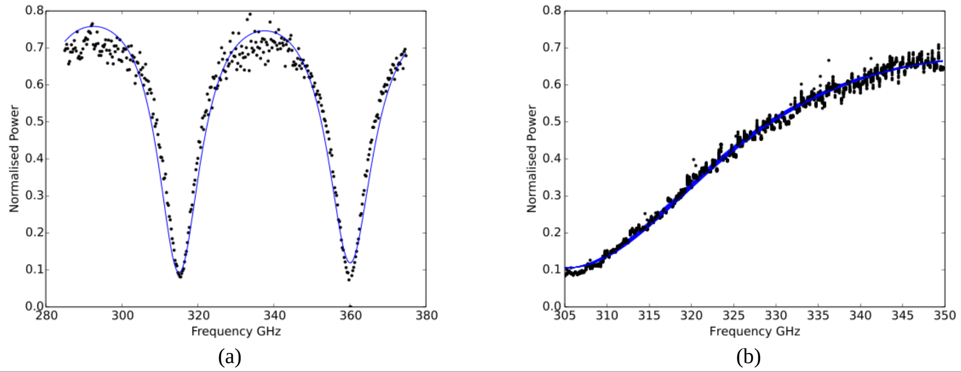

Figure 2: Reflection spectra from (a) YTZP and (b) YSZ thermal barrier coating sample in the GHz frequency range.

The curve fits shown in Figure 2 are a single layer Fresnel fit of the observed fringes which accurately capture the large scale frequency-dependent reflectivity. Figure 2a shows some additional fringe complexity that may require extension of the Fresnel model to, e.g. a full Transfer Matrix Method.

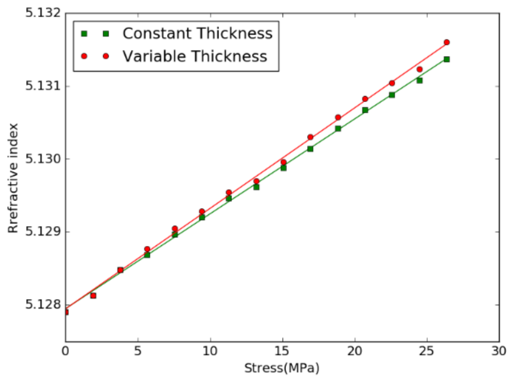

Figure 3: Stress Optic Coefficient of bulk YTZP sample assuming constant sample thickness during loading and variable thickness during loading.

The single layer Fresnel fits to the measured reflection spectra are sufficient to allow the derivation of some of the material properties of the samples, including the refractive index. Figure 3 shows the stress-optic behavior of the bulk YTZP where the change in the refractive index of the material under load is a linear function of the applied stress.

Conclusions

The development of the GHz and THz polariscope systems has permitted different material properties of ceramic coating systems to be measured. This work has identified and measured a stress-optic coefficient in ceramic materials for the first time, indicating that photoelasticity is possible directly in these materials, without the need to build a photoelastic model that is transparent at visible wavelengths. This approach may allow an assessment of the thermal barrier coating lifetimes to be made with a view to identifying those coatings with a high probability of failure during operation.

References

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2. P. Schemmel, G. Diederich, and A. J. Moore, *"Measurement of direct strain optic coefficient of YSZ thermal barrier coatings at GHz frequencies,"* Opt. Express 25, 19968-19980 (2017) https://doi.org/10.1364/OE.25.019968

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